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GIS assessment of large CSP plant in Duqum, Oman

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ABSTRACT

This paper discusses solar power prospects in Wilayat Duqum in Oman. First, the geographic and topographic information about the selected region is presented. The methodology of producing solar radiation map for Duqum using GIS tools is then presented. The results obtained show very high potential of solar radiation over Wilayat Duqum during the whole year. A slope analysis has allowed calculating the yearly electricity generation potential for different concentrated solar power (CSP) technologies such as the parabolic trough, parabolic dish, tower, and concentrated PV. Based on the development plan of the Duqum region, and the topologies of the land areas in the region, it is suggested that, for the CSP technologies requiring large amount of water for washing the mirrors, the selected area is a flat land (slope $< 1\%$) located proximity to the sea ($\sim$2 km) inside a total industrial area of around 50 km^2, hence, allowing easy future expansion of the plant. It was proposed to start with a 100 MW power plant which is expected to consume about 2.4 km^2 of flat land for the parabolic trough CSP technology. The total calculated potential of yearly electricity generation would be about 2.3 TWh. If half of the selected land (0.5×50 km^2) is reserved for future expansion of the plant, the total future capacity can attain 1 GW of electric power. The selected area can also accommodate in the future different types of CSP technologies as they mature with time.

Contents

1. Introduction

The very slow renewable energy development in the Middle East in general and in the Sultanate of Oman in particular, facing a multitude of policy and administrative barriers – including highly subsidized cheap electricity competing with renewable technologies – as well as the lack of adequate fiscal incentives to consumers for their private installation, has prevented the spread of renewable energies in the region and the country because of general fear and distrust of renewable energies. Flows of foreign technology and finance were also way below real needs. However, the previous known fear and distrust of renewable energies on the part of the Sultanate of Oman as an oil and gas producing country has recently changed into a realization that renewable energy can be an essential component of its national energy supplies, as well as a global strategic option for both extending the life of oil and gas reserves and reducing carbon dioxide emissions and thus contributing in combating climate change.

The use of solar energy in the Sultanate of Oman has been limited to very few applications such as city street lighting, park

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meters, and few telecommunication stations in remote areas. Positive investment climate, strong property rights, and low tax regimes, adequate regulatory framework, with established participation in the power sector from leading international firms, will certainly provide incentives to more solar energy applications in the country. However, without an accurate database and knowledge of most appropriate locations of renewable energy applications in the country, investment in renewable energy will not be efficient and profitable. This can be achieved by producing solar radiation maps for different regions in the Sultanate of Oman.

Innovations in solar radiation mapping are now contributing to the rapid growth of solar energy market in many countries. The developed solar radiation maps benefit everyone from home-owners and solar-panel installers to the developers and financiers of large-scale power projects, industry experts, and governments. In addition, with the present worldwide credit crisis and the perilous world and local economy, precise solar maps will be increasingly important as investors seek assurance that deals will be really profitable. Better information means quicker decisions saving money and bringing renewable energy resources into production more quickly. Therefore, finding the right location for installing solar energy systems is very crucial.

Developing solar radiation maps for a given region means creating illustrations revealing the geographical distribution of solar radiation covering that specific region. A solar radiation map demonstrates solar energy potentials of a specific region and provides information which is useful for optimum site-selection of a solar energy system. A solar radiation map can be generated by using solar radiation data obtained from measurement stations. However, such a method is not applicable to many parts of the globe due to insufficiency of measurement stations. One solution is to use satellite-derived solar radiation data to create solar radiation maps.

In the past 35 years, several methods for estimating solar radiation from satellite data have been developed and used [1–43]. However, only few detailed studies have been carried out specifically for tropical countries such as the Sultanate of Oman. This paper presents a study that aimed at developing the first geographical mapping models to locate the most appropriate site for large concentrated solar power (CSP) plant in Wilayat Duqum in the Sultanate of Oman.

2. Location and topography of Wilayat Duqum

The Sultanate of Oman occupies the south-eastern corner of the Arabian Peninsula and is located between latitudes 16°40′ and 26°20′ North and longitudes 51°50′ and 59°40′ East (Fig. 1). It has a coastal line extending almost 3165 km, from the Strait of Hormuz in the North to the borders of the Republic of Yemen, overlooking three seas; the Arabian Gulf, Gulf of Oman and the Arabian Sea [44].

The Sultanate of Oman borders Kingdom of Saudi Arabia and the United Arab Emirates in the West; the Republic of Yemen in the South; the Strait of Hormuz in the North and the Arabian Sea in the East.

Wilayat Duqum is located in the south-eastern corner of Al-Wusta, neighboring the Wilayat of Mahut in the north, the Wilayat of Jazur in the south, the Wilayat of Haima in the west and in the east the Arabian Sea, shown in Fig. 1. There are presently more than 4276 inhabitants living in about 23 villages [45].

3. Expansion plan of Wilayat Duqum

Duqum has been hardly a destination for the average tourist or leisure-traveler, leave alone industrialists. But by 2013, the Sultanate of Oman's most comprehensively planned town is expected to blip on the global industrial radar like no other Omani city [46]. Few years ago, a comprehensive master plan was

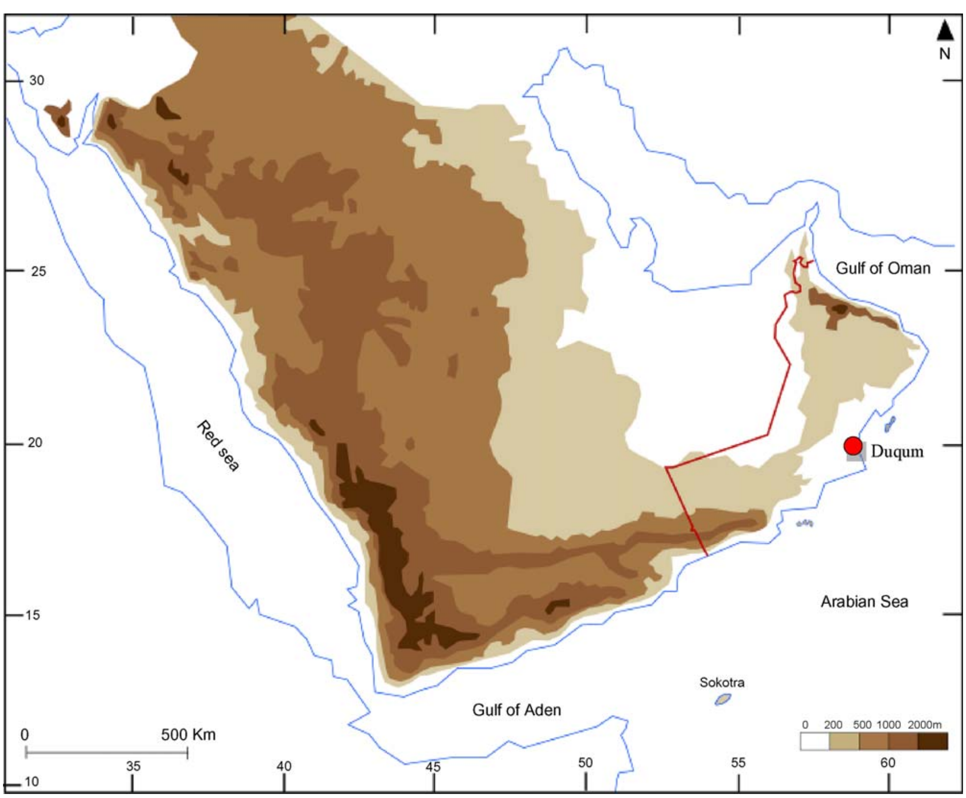

Fig. 1. Location of Oman in the Arabian Peninsula.

prepared for Duqum by the Supreme Committee for Town Planning, Sultanate of Oman. The master plan designated areas for airport, petroleum refinery and oil storage facilities along with downstream industries, a fishing harbor with fishery related industries, free trade zones, general industries and tourism projects (see Fig. 2). It has planned a complete residential town with a Town Centre and all modern amenities [46].

The purpose behind developing Duqum is to export Gulf's crude oil from an Omani port. Outline of the plan is to export crude oil, which is produced in the Gulf region and transported through

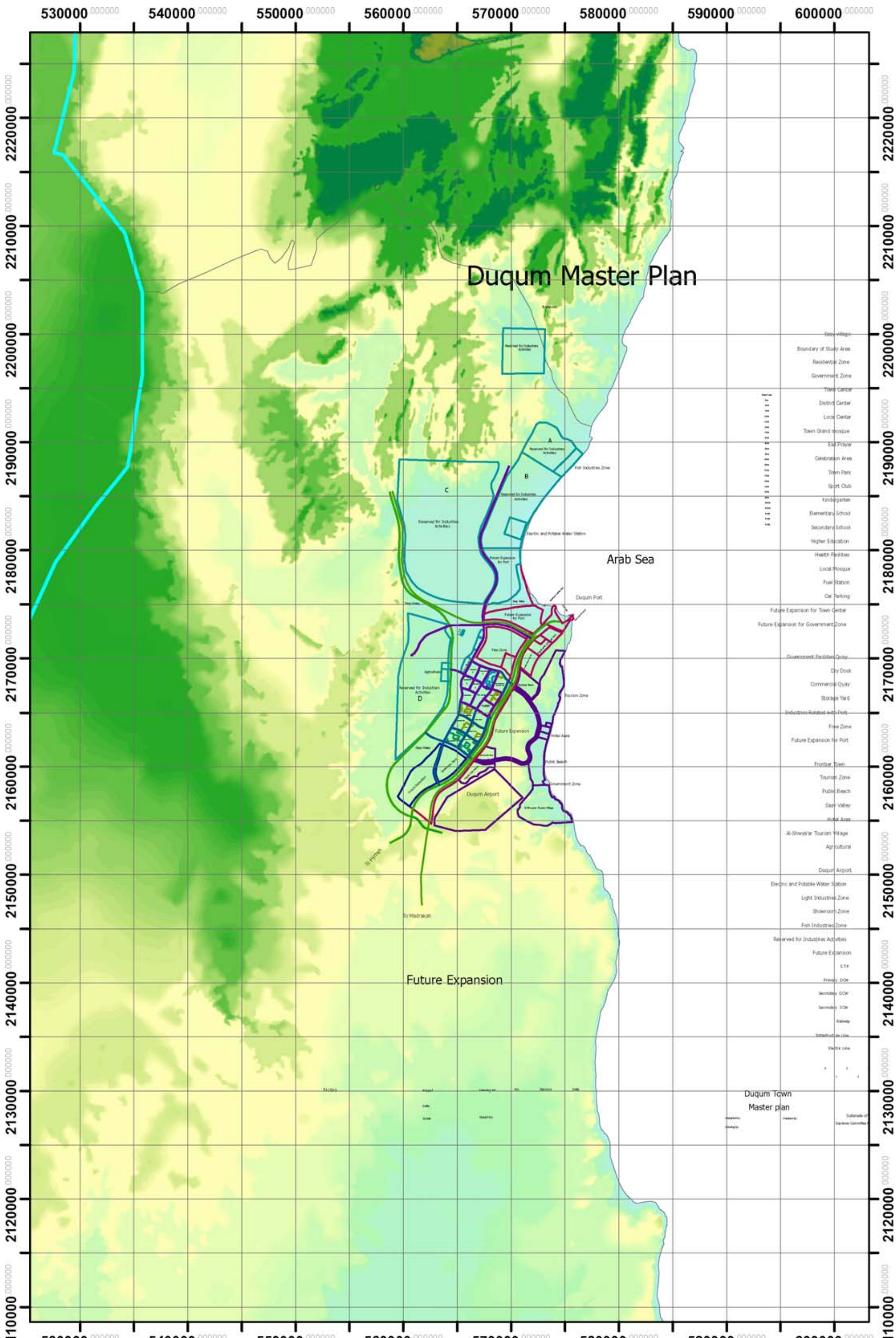

Fig. 2. Wilayat Duqum digital elevation model with master development plan.

pipeline to Omani port. Positioned as it is on the Gulf of Oman, with the Strait of Hormuz and the Arabian Sea at its north-eastern end, and with its long coastline running south along the Arabian Sea, the government believes Duqum is strategically the most preferred location for this port.

The biggest catch for Duqum could be its mineral export capability. The total dry bulk cargo handled at Duqum in 2025 is estimated to be four million tones. The exports of aggregate will comprise limestone for steel industry and limestone fillers for other industries as well silica sand/quartzite. Most importantly, the port will handle a substantial portion of the fish export from Oman. It is estimated that in 2025, the total fish catch of Sultanate of Oman will be 250,000 ton, and about 50% of it will be exported. Share of the catch and the export from the ports are likely to be like this: Sultan Qaboos – 35%, Duqum – 27%, and Salalah – 13% [46].

The only responsible company for electric power generation, transmission, supplying and distribution for Duqum region is the Rural Areas Electricity Company (RAECO). Estimating and forecasting the future load demand for five coming years for the Duqum expansion project is one of the tasks that the RAECO has already predicted. The total forecasted load demand will be increasing gradually in the coming 5 years. As a result for Duqum future plan supervised by the Supreme Committee for Town Planning, the demand load is expected to approach 100 MW by 2013. Consequently, constructing a 100 MW power generation plant based mainly on solar energy will be practically very attractive project for Wilayat Duqum. On the other hand, the Oman Electricity Transmission Company has already planned the construction of a 400 kV transmission line which is expected to reach Duqum and connect it to the main grid by year 2013. This will allow for further future expansions of the power generation from renewable energy and injecting it into the grid during peak load hours.

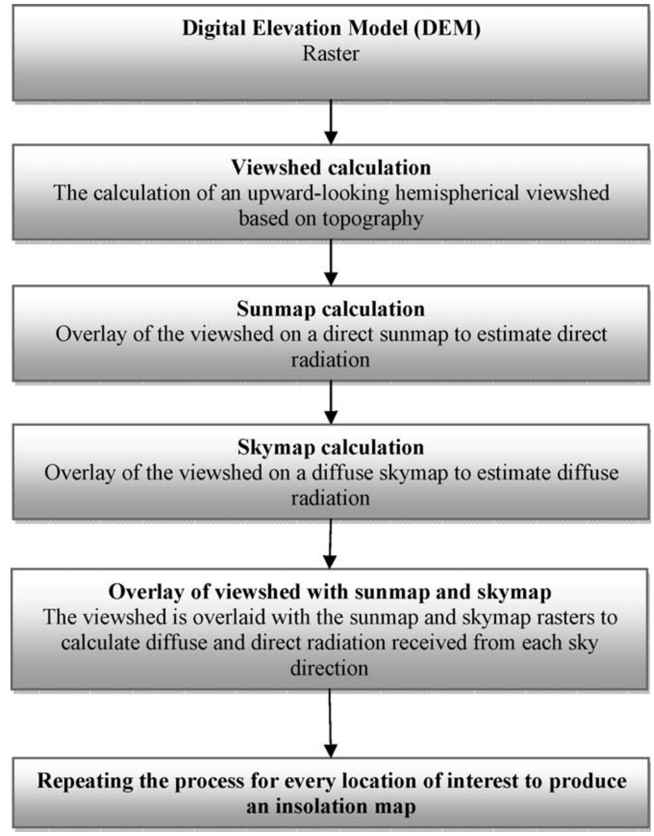

Fig. 4. Steps followed to calculate solar radiation on a DEM using ArcMap.

4. Developing solar radiation maps for Duqum using ArcGIS

With landscape scales, topography is a key factor that determines the spatial variability of radiation. Variation in elevation, orientation (slope and aspect), and shadows cast by topographic features all affect the amount of radiation received at different locations. This spatial variability also changes with time of day and time of year. The solar radiation analysis tools, in the ArcGIS Spatial Analyst extension, enable to map and analyze the effects of the sun over a geographic area for specific time periods. It accounts for atmospheric effects, site latitude and elevation, steepness (slope) and compass direction (aspect), daily and seasonal shifts of the sun angle, and effects of shadows cast by surrounding topography as shown in Fig. 3.

Incoming solar radiation originates from the sun, is modified as it travels through the atmosphere, is further modified by topography and surface features, and is intercepted at the earth's surface as direct, diffuse, and reflected components. The sum of the direct, diffuse, and reflected radiation forms the global solar radiation. In general, direct radiation is the principal component of total radiation, and diffuse radiation is the second largest component. The solar radiation tools in ArcGIS Spatial Analyst [47] do not include reflected radiation in the calculation of total radiation. Therefore, the total radiation is calculated as the sum of the direct and diffuse radiation. The solar radiation tools can perform calculations for point locations or for entire geographic areas. This involves six steps as described in Fig. 4.

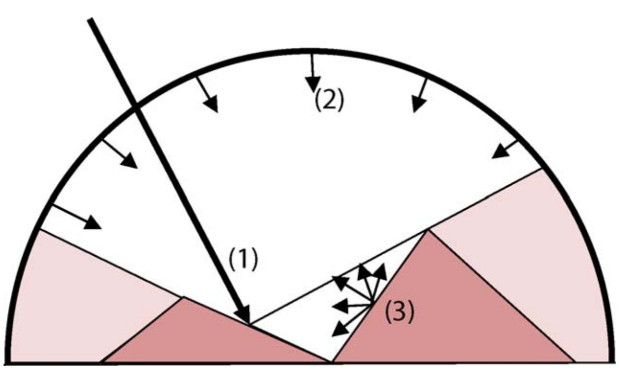

Fig. 3. The three sources of energy on a slope: (1) direct or beam radiation from the sun; (2) diffuse radiation from the sky, where a portion of the overlying hemisphere may be obstructed; and (3) diffuse and direct radiation reflected off of nearby terrain [27].

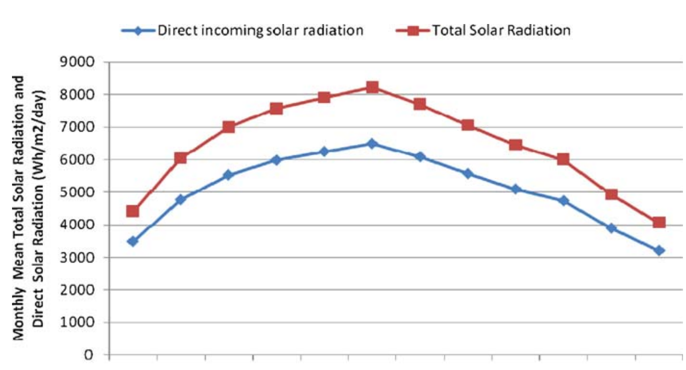

Fig. 5. Monthly mean total solar radiation and direct solar radiation per day for all Wilayat Duqum.

5. Results and discussions

5.1. Resolution of the DEM

It is important to select an appropriate resolution of the DEM of Oman that can be used with ArcMap tool (part of ArcGIS) so that it can run faster without jeopardizing the accuracy of the results. There is a compromise between obtaining highly accurate results and the software computational time. Therefore, a resolution of $100 \times 100\,m^2$ cells was adopted which gave a relatively short running time of solar radiation area calculation.

5.2. Generated solar radiations and maps

The average daily solar radiations and direct incoming solar radiation over all the lands of Duqum were calculated for every month. Fig. 5 summarizes the obtained results.

Notice that the highest solar radiation per day (8217 $Wh/m^2/day$) is obtained during the month of June (summer solstice) and the least one (4059 $Wh/m^2/day$) is obtained in December (winter solstice). It is clear that the solar potential is high during the whole year.

Fig. 6 shows in green (light color) the land area classification of Duqum region with slopes less than 1% and calculated surfaces

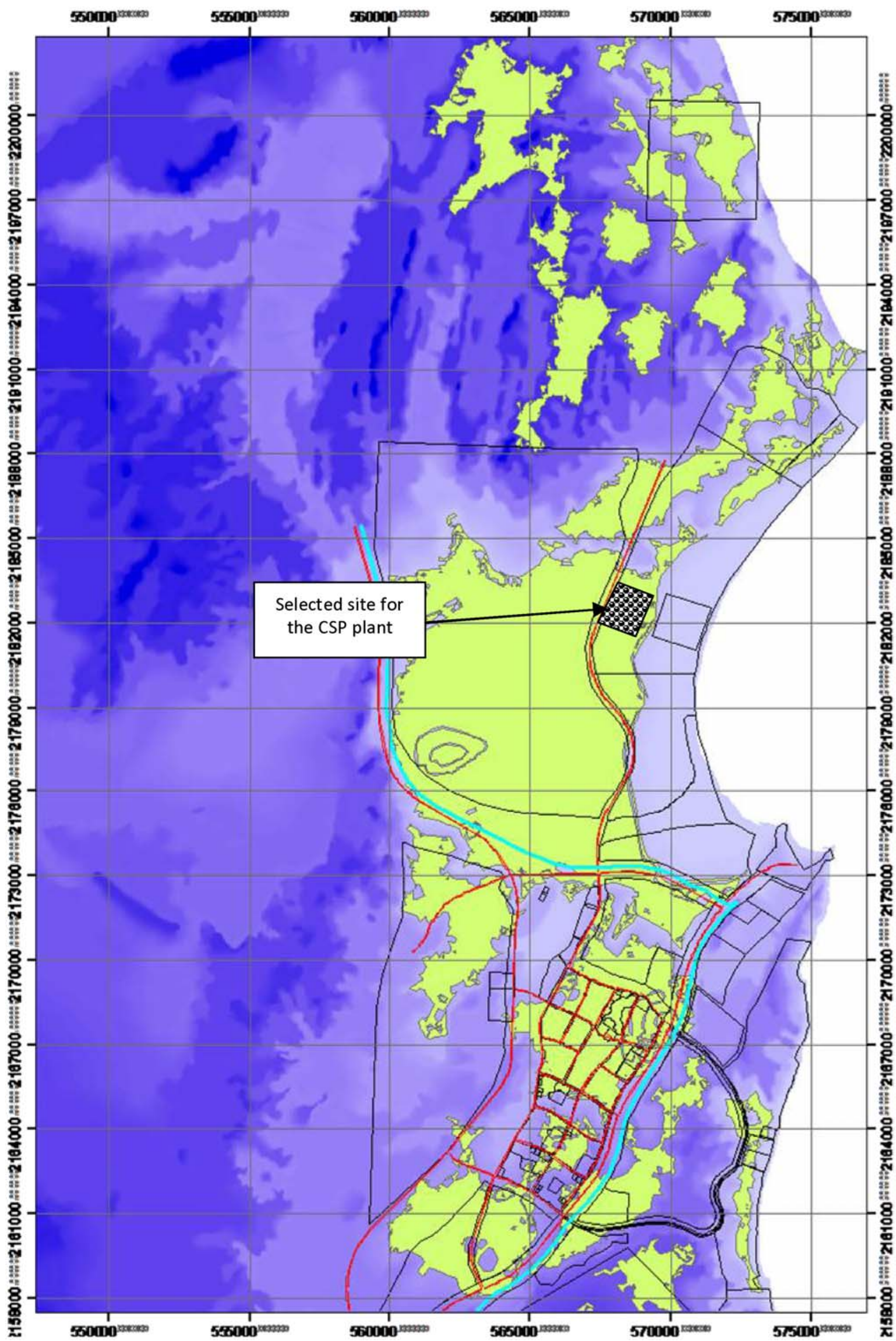

Fig. 6. Solar radiation distribution and classification over the Duqum region.

Table 1
Annual solar radiation and energy.

Slope (%)	Yearly solar radiation (MWh/m^2)	Estimated area for 100 MW CSP plant (km^2)	Capacity factor (%)	Total solar energy (TWh/year)
<1	2.35701	2.400	40	2.319

larger than 2.5 km^2. Note that only the most interesting portion of Wilayat Duqum is zoomed in Fig. 6. It is clear that a large portion of the lands has slopes below 1% (flat land) and has surfaces bigger than 2.5 km^2. This signifies that it is easy to implement large CSP plants with different technologies such as parabolic trough without storage (PTNS), parabolic trough with storage (PTWS), tower, parabolic dish, and concentrated PV (CPV) technologies without additional and expensive work over to flatten the lands.

The land areas for each technology type, along with the potential generation capacity in MW and GWh/year, are presented in Table 1, where the average estimated required land for the CSP plant and the average capacity factor were selected arbitrarily equal to 2.4 km^2 and 40%, respectively. The total calculated potential of yearly electricity generation would be more than 2.3 TWh.

Table 2, summarizes the results obtained for the five CSP technologies mentioned above. The capacity potentials for each technology were estimated from [48]. The efficiency of each CSP technology was selected based on the average values of the ranges published in the literature.

Table 2 shows that, with each CSP technology, there is a very high potential to generate sufficient energy for Duqum future expansion.

Dish and CPV are modular in nature, with single units producing power in the range of 10–35 kW. Thus, dish and CPV systems could be used for distributed or remote generation applications, and can be sited as large plants by aggregating many units. Dish and CPV systems have the potential advantage of mass production of individual units, similar to the mass production of automobiles.

Trough and tower plants, with their large central turbine generators and balance of plant equipment, have a cost advantage of economy of scale—that is, cost per kW goes down with increased size. Trough and tower systems have the potential advantage over dish and CPV systems in that an amount of dispatchability can be designed into the system with thermal storage or the use of hybrid fossil. Dispatchability allows the solar plant to generate electricity during short duration cloudy periods or to generate electricity into the evening after sunset. This gives the plant potential to receive capacity credit, and provides the ability to more closely match the utility peak load profile. This assures availability and security of power supply.

At this time, dish–stirling systems have not been configured to provide hybrid fossil capability. CPV systems could, of course, make use of battery energy storage; however, battery storage is comparatively inefficient and expensive, and has not been considered in this study. Should battery storage system costs decrease substantially, and efficiency increases, the use of storage with CPV would certainly be an option in the future.

Table 2
Summary of obtained results.

CSP technology	PTNS	PTSWS	Tower	Dish	CPV
Capacity potential (MW/km^2)	43.26	30.82	22.38	49.26	41.11
Efficiency (%)	18	18	19	27.5	41
Total capacity (MW)	104	74	54	118	99
Yearly electric power generation potential (GWh/year)	1,018	1,018	1,075	1,556	2,319

The power tower type may not be appropriate to use in the Duqum area because of the vicinity of the airport. Consequently, based on the above analysis, it is recommended to use the parabolic trough type with or without storage capabilities. Based on this choice, it is recommended that plant be situated proximity to sea because it requires large amount of water to cooling and for mirrors' washing. However, being very close to the sea increases the risks of corrosion and decreases the direct solar radiation because of high humidity that diffuses the incident solar radiation.

Based on the development plan of Duqum, and the topologies of the land areas in the region, it is suggested that, for the CSP technologies requiring large amount of water for cooling and mirrors' washing, the selected area is a flat land (slope $<$ 1%) located proximity to the sea ($\sim$2 km) inside a total projected industrial area of around 50 km^2, hence, allowing easy future expansion of the plants. It was proposed to start with a 100 MW power plant which is expected to consume around 2.4 km^2 of flat land for the parabolic trough CSP technology electric power plant. The total calculated potential of yearly electricity generation would be about 2.3 TWh (see Table 1). If half of the selected land (0.5×50 km^2) is reserved for future expansion of the plant, the total future capacity can attain 1 GW of electric power. The selected area can also accommodate in the future different types of CSP technologies (i.e., Fresnel technology) as they mature with time.

6. Conclusion

This paper presented a study on solar electricity prospects for Duqum in the Sultanate of Oman based on the master development plan and GIS solar radiation map. This map is the first of its kind to be published in the literature and will benefit government's policy leaders to be proactive in the development of solar energy and will help create viable solar energy market in the region. The methodology followed to generate such map was based on the ArcMap tools embedded in the ArcGIS Software. It is important to note that in situ measurement realized with pyranometers, will not be able to capture the spatial variability in radiation caused by topography as the GIS does.

The results obtained showed very high potentials of solar energy and solar electricity generation in Duqum during the whole year. The high ratio of sky clearness and the geographical location of Oman played an important role in awarding this country with a very high potential of solar electricity generation.

Based on the solar radiation map and the master plan for the development of Duqum, it was possible to select a suitable location for a 100 MW CSP plant. The selected site is located about 2 km far from the coast and has an area of about 50 km^2. This site was originally reserved for future industrial expansion. However, if only half of this land is used for electric power generation the plant capacity can easily rise up to 1 GW. The plant can also combine both electricity generation and water desalination.

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